Alternative Stripper Configurations for CO_2 Capture by Aqueous Amines

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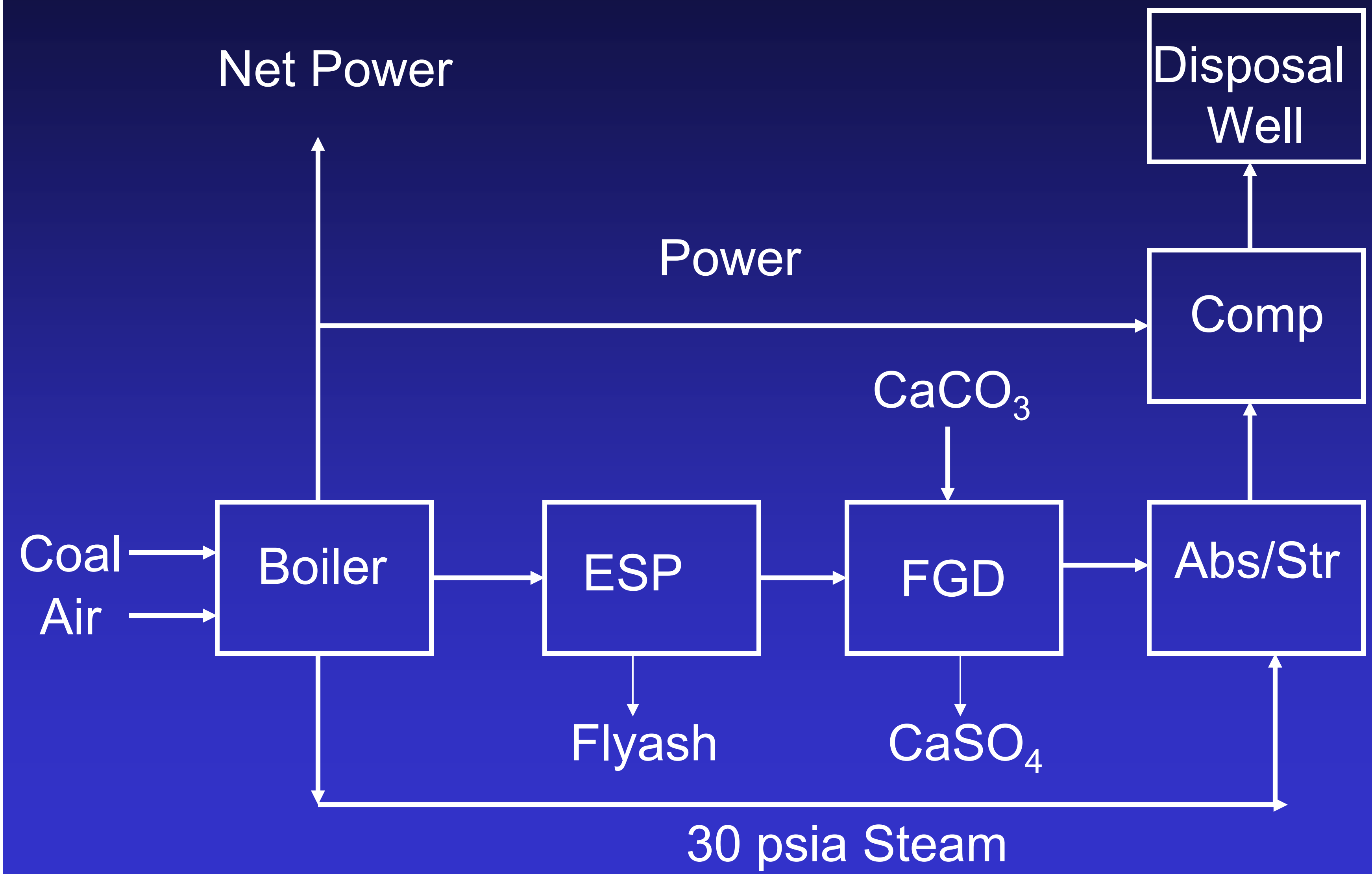
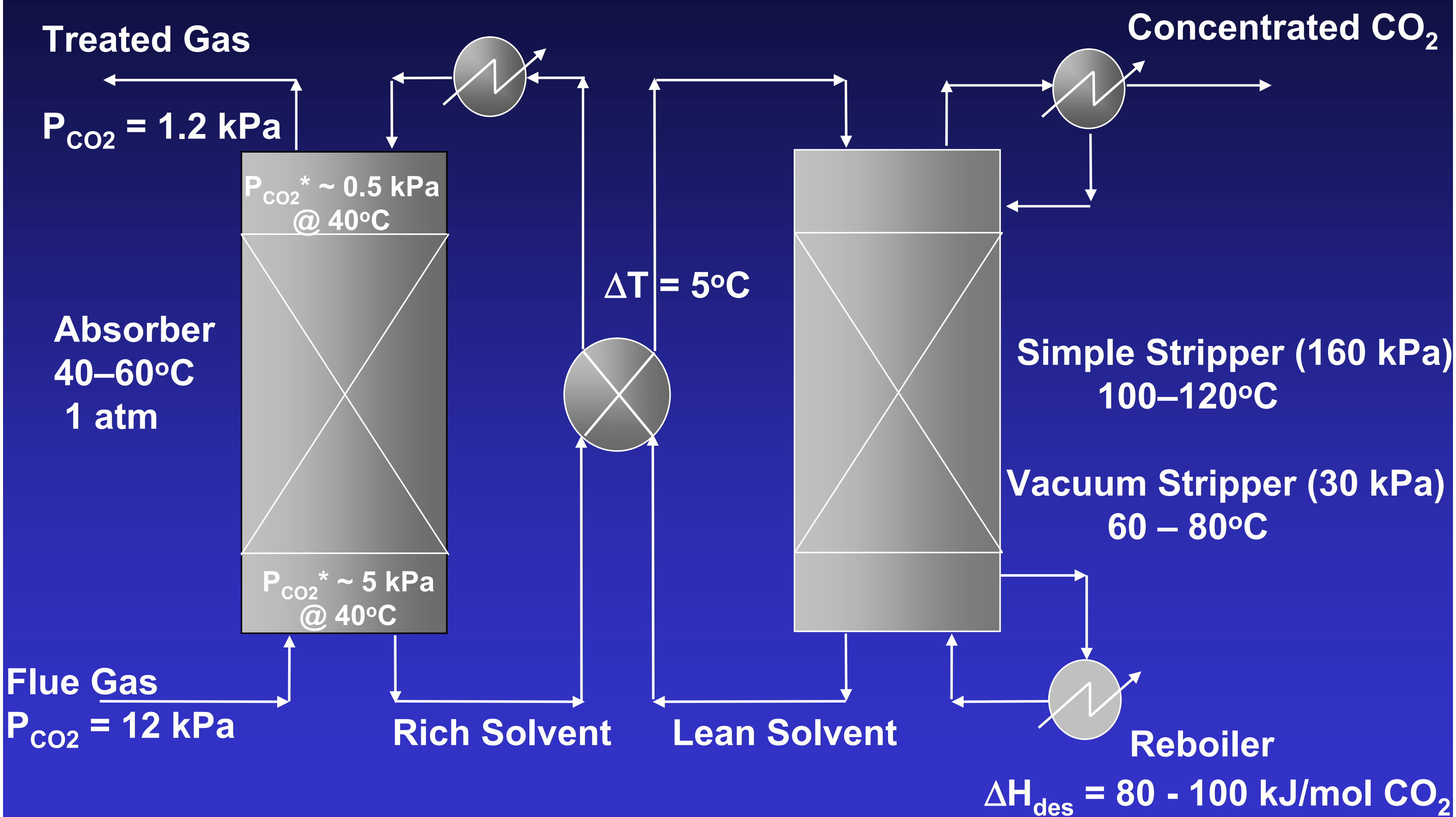
Outline

- Introduction
- Practical Problems and Solutions
  - Improved Solvents
  - Matrix Stripper
- Equilibrium Model Description and Results
- Conclusions

System for CO_2 Capture and Sequestration



Modified Baseline Absorber/Stripper Configuration



7m (30-wt%) monoethanolamine (MEA)

- Industrial state-of-the-art,Demonstrated Tech
- Economic
- Good mass transfer rates

Practical Problems

- High Energy Requirement
  - Reboiler duty (80% of operating cost)
- Amine degradation and corrosion
  - Make-up costs
- High Capital Cost
  - Large Absorption and Stripping Columns

Focus of research

Reduce energy consumption (reboiler duty)

$$Q_{reb} = \Delta H_{des} + \left(\frac{n_{H2O}}{n_{CO2}} \Delta H_{vap} \right) + \left(\frac{L \quad Cp \quad \Delta T}{n_{CO2}} \right)$$

Approach to reducing energy consumption

- Alternative solvents to 7m (30-wt%) MEA
  - Heat of absorption
  - Capacity
  - Rates of reaction with CO_2
- Innovative process flow schemes
  - Understand stripper operation
  - Energy Integration

Improved Solvents

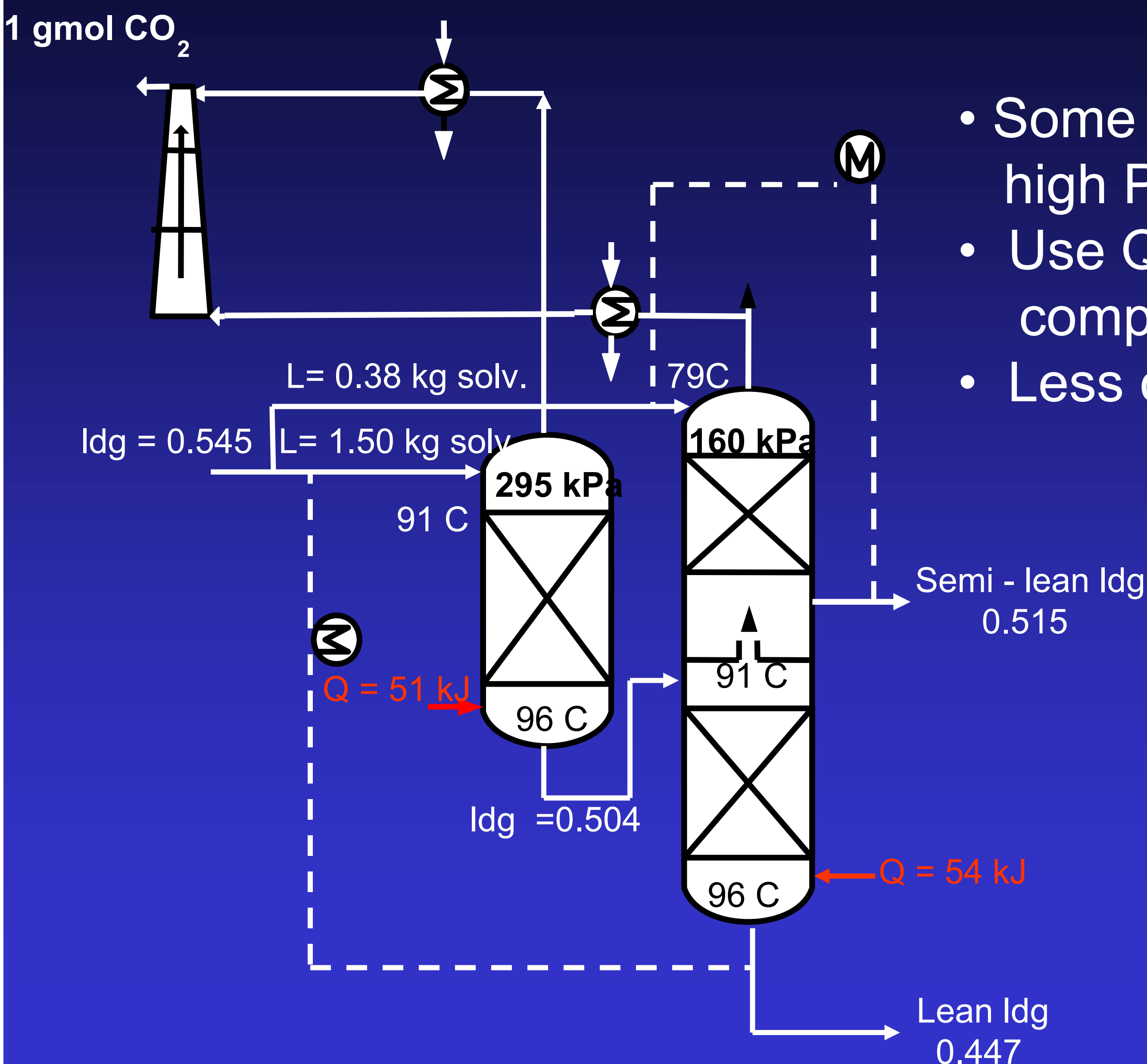
- Lower energy consumption/better mass transfer/less degradation and corrosion than MEA
  - promoted K_2CO_3 (K_2CO_3/PZ)
  - promoted MEA (MEA/PZ)
  - promoted tertiary amines (MDEA/PZ)
  - mildly hindered amines (KS-1)

- Greater capacity (4m K^+/4m PZ, MDEA/PZ, KS-1)
  - less sensible heat requirement

- Enhanced mass transfer (PZ/K_2CO_3, MEA/PZ)
  - less capital cost, closer approach to saturation

- Less degradation and corrosion (PZ/K_2CO_3,KS-1,KS-2,KS-3)
  - reduced make-up costs

Matrix Stripper



- Some CO_2 recovered at high P
- Use Q instead of W for compression
- Less comp. downstream

Evaluation in Aspen Custom Modeler (ACM)

Features

- Flash section, 10 sections, Equilibrium reboiler
- Compression to 330 kPa

VLE

$$P_{CO2}^* = f\,(T, ldg)$$

Model Assumptions

- Well-mixed L & V phases
- 40%,100%,100% Murphree Eff. for CO_2, T & H_2O
- Negligible vaporization of solvent

Performance of Strippers
Concept of Equivalent Work (W_{eq})

Why W_{eq} ?

- Compare stripper configurations on same basis.
- Compare Q and W.

$$= 0.75\, Q_{reb} \left[\frac{(T_{reb} + 10) - 313}{(T_{reb} + 10)} \right] + W_{comp}$$

(75% Adiabatic Efficiency in Compressor)

Generic Solvent Characteristics

Solvent	6.4m K^+/ 1.6m PZ	5m K^+/ 2.5m PZ	4m K^+/ 4m PZ	7m MEA	MEA/ PZ	MDEA/ PZ	KS-1
ΔH_{abs} (kJ/gmol)	50	63	67	84	85	62	73
Rich P_{CO2}^* (kPa) @ 40°C	5	5	7.5	5	7.5	7.5	5
Capacity $\left[\frac{\text{mol } CO_2}{\text{kg } H_2O}\right]$	0.91	0.93	1.34	0.85	1.12	1.77	2.11
VLE Sources	Cullinane (2005)			Freguia (2002)		Posey (1996)	MHI

Predicted Performance of Different Solvents and Flow Schemes
(90% removal, P_{reb} = 160 kPa, $\Delta\mathbf{T}$ = 5°C, P_{final} = 330 kPa)

	4m K^+/ 4m PZ	7m MEA	MEA/PZ	MDEA/PZ
	Equivalent Work (kJ/gmol CO_2)			
Baseline (10°C)	21.4	22.3	20.0	18.3
Modified Baseline (5°C)	19.0	19.7	17.5	17.2
Matrix	15.6	18.0	15.7	15.1

Effect of ΔH_{abs} on energy requirement (90% removal, $\Delta T = 5^oC$, P_{final} = 330 kPa)

	6.4m K^+/ 1.6m PZ	5m K^+/ 2.5m PZ
Capacity $\left[\frac{mol\ CO_2}{kg\ H_2O}\right]$	0.91	0.93
ΔH_{abs} (kJ/gmol)	50	63
	Equivalent Work ($kJ/gmol\ CO_2$)	
Modified Baseline	27.4	22.6
Vacuum	23.7	23.1

Effect of capacity on energy requirement

(90% removal, P_{reb} = 160 kPa, ΔT = 5°C, P_{final} = 330 kPa)

	5m K^+/ 2.5m PZ	MDEA/PZ
ΔH_{abs} (kJ/gmol)	63	62
Capacity $\left[\frac{\text{mol } CO_2}{\text{kg } H_2O}\right]$	0.93	1.77
	Equivalent Work (kJ/gmol CO_2)	
Modified baseline	22.6	17.2
Matrix	21.7	15.1

Solvent performance for simple strippers

(90% removal, ΔT = 5°C, P_{final} = 330 kPa)

	6.4m K^+/ 1.6m PZ	MDEA/PZ	7m MEA
ΔH_{abs} (kJ/gmol)	50	62	84
P (kPa)	Equivalent Work (kJ/gmol CO_2)		
160	27.4	17.2	19.7
30	23.7	19.8	22.6

Energy requirement for separation and compression to 10 MPa

Separation Method	W_{sep}	W_{comp}	Total W_{eq}
	kJ/gmol CO_2		
Ideal Sep., (40^{o}C,100 kPa) Isothermal Comp.	7.3	10.8	18.1
Ideal Sep., (40^{o}C,100 kPa) 75% Adiabatic Comp. In 5 stages	7.3	16.8	24.1
Ideal Membrane (40^{o}C) (75% adiabatic comp. eff. in 5 stages)	11.6	16.8	28.4
7m MEA, 10^{o}C, 160 kPa	19.5	14.0	33.5
7m MEA, 5^{o}C, 160 kPa	16.8	14.0	30.8
Matrix (MDEA/PZ)	14.6	11.6	26.2

Conclusions

- MEA/PZ and MDEA/PZ are solvent alternatives to 7m MEA.
- The matrix configuration is an attractive stripper configuration.
- At a fixed capacity, solvents with high ΔH_{abs} require less energy for stripping (temperature swing effect).
- Less energy is required by high capacity solvents with equivalent ΔH_{abs}.
- Matrix using MDEA/PZ offers 22% and 15% energy savings over the baseline and the modified baseline with stripping and compression to 10 MPa.
- Typical predicted energy requirement for stripping and compression to 10 MPa (30 kJ/gmol CO_2) is about 20% of the output from a 500 MW power plant with 90% CO_2 removal.

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